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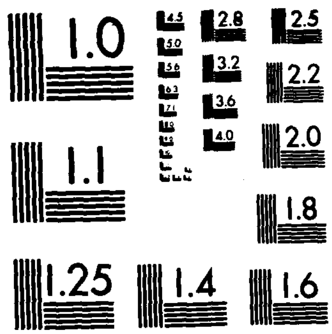

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Wind tunnel tests, utilizing a one-sixth scale model of a proposed interceptor configuration, were carried out to assess the feasibility of variable Mach number wall jets for propulsion and control applications at high altitude. The objective of this preliminary study was to assess the performance of such a thruster at high altitude where an enormous billowing of underexpanded exhaust plumes may cause a variety of problems. Included in these is sensor obscuration as a result of the upstream migration of low momentum nozzle boundary layer contaminants. The partially-bounded nature of the wall jet configuration, as well as its variable Mach number capabilities favorably impact this problem. In addition, the configuration admits a simple staging, wherein the nose may explosively separate from the afterbody prior to impact for damage enhancement. The tests indicated that no degradation in thrust is inherent to the configuration. Additional flowfield visualizations are required to quantify the obscuration problem at highly underxpanded conditions. Subsequent tests shall also assess the generation of control sideforces with an asymmetric nozzle throat.

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Final Report

Contract No.: DASG60-87-C-0087

VARIABLE MACH NUMBER WALL JETS FOR CONTROL/PROPULSION ON HYPER-VELOCITY PROJECTILES/INTERCEPTORS: TESTS WITH AN EXISTING MODEL

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Chief Scientist

1988

The views, opinions, and/or findings contained in this report are those of the author and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other official documentation.

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Certification of Technical Data Conformity

The contractor, The Hokenson Company, hereby certifies that, to the best of its knowledge and belief, the technical data delivered herewith under Contract No. DASG60-87-C-0087 is complete, accurate and complies with all requirements of the contract.

Date: 3/18/88

Official: Gustave J. Hokenson

Gustave J. Hokenson, PhD
Chief Scientist

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Executive Summary

The huge expansion of chemical propulsion exhausts from hypervelocity interceptors and projectiles at high altitude results in a billowed plume. This plume interferes with the freestream flow and allows low-energy nozzle boundary layer contaminants to migrate upstream toward the sensor locations. Given a configuration in which a relatively simple mechanical control could adjust the exit Mach number and direction of the exhaust, many of the current problems associated with chemical propulsion exhausts may be alleviated. By utilizing an existing model, the effectiveness of a wall jet on hypervelocity vehicles for propulsion and/or control applications has been evaluated experimentally. The model was immersed in a low density flow with the wall jet flowfield observed and net axial force measured as a function of the jet Mach number and stagnation pressure. The jet exit Mach number was varied from 2 to 10. Model design modifications have been prepared that would be required to allow the jet to be non-axisymmetric and generate cross-range forces as well as operate in a staged mode with the conical nose separating impulsively from the skirt. On the basis of these flowfield visualizations and axial force measurements, the plan for a comprehensive series of wind tunnel tests at a later phase also has been formulated.

Discussion

The Phase I SBIR program reported upon here addressed the problems associated with billowed plumes that result from chemical propulsion exhausts at high altitude. Of primary interest is the upstream migration of low energy boundary layer contaminants which may obscure on-board sensors. In addition, the meandering plume on maneuvering vehicles is, itself, a potential source of obscuration. In an effort to make a direct contribution towards the (whole or partial) resolution of these issues, a specific existing configuration was proposed for experimental investigation.

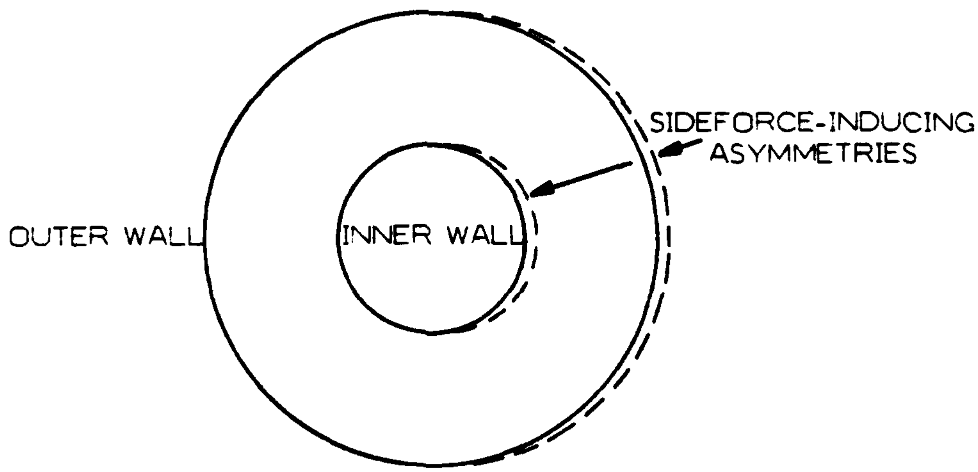
Self-explanatory schematics of the variable Mach number wall jet model and an enlarged view of the injection port are presented in Figures 1 & 2 with dimensions presented in units of inches. Photographs of the actual model tested are hown in Figures 3 & 4. The hypothesis which motivated the proposal was that such a partially-bounded thrust jet may prove, in the net, inherently beneficial due to its geometry, relative to the aforementioned billowing and migrating plume obscuration problem. In addition, the design has at least two other facets which should be of interest relative to the hypervelocity interceptor/ projectile application, namely:

- Simple variable Mach number capability, and
- Staging such that the forebody may readily separate from the base at the opportune time.

These aspects of the design are depicted in the schematic in which it is clear that, by moving the model forebody closer to the frustrum, the nozzle throat area is reduced. On the model, this is done via a male thread on the head of a shaft which connects the

two parts of the model and attaches to a female thread in the forebody. Therefore, by rotating the forebody, the relative axial positions between the two parts of the model, and thus the throat height, may be varied. For the model the jet is axisymmetric and, therefore, a relatively uniform jet Mach number is produced as shown in Figure 5. In order to generate non-uniform exhausts and thereby create a sideforce, non-axisymmetric inner and outer walls of the nozzle are required. For example, if both the inner and outer walls had a bulge on one side, as shown in the following schematic:

NOZZLE THROAT GEOMETRY



As the forebody is rotated, the nozzle throat closes but the exhaust is azimuthally uniform only every 360° of rotation. At intermediate angles, the thrust is non-axisymmetric and a sideforce is readily produced. Separation of the forebody from the frustrum is accomplished simply by utilizing explosive bolts.

Within the model is located a strain gage load cell shown in Figures 6 and 7. Typical C_T results measured on the model by the load cell as a function of the injection Mach number and pressure are shown in Figure 8. Note that the high Mach number condition corresponds to a small throat area and mass flow rate.

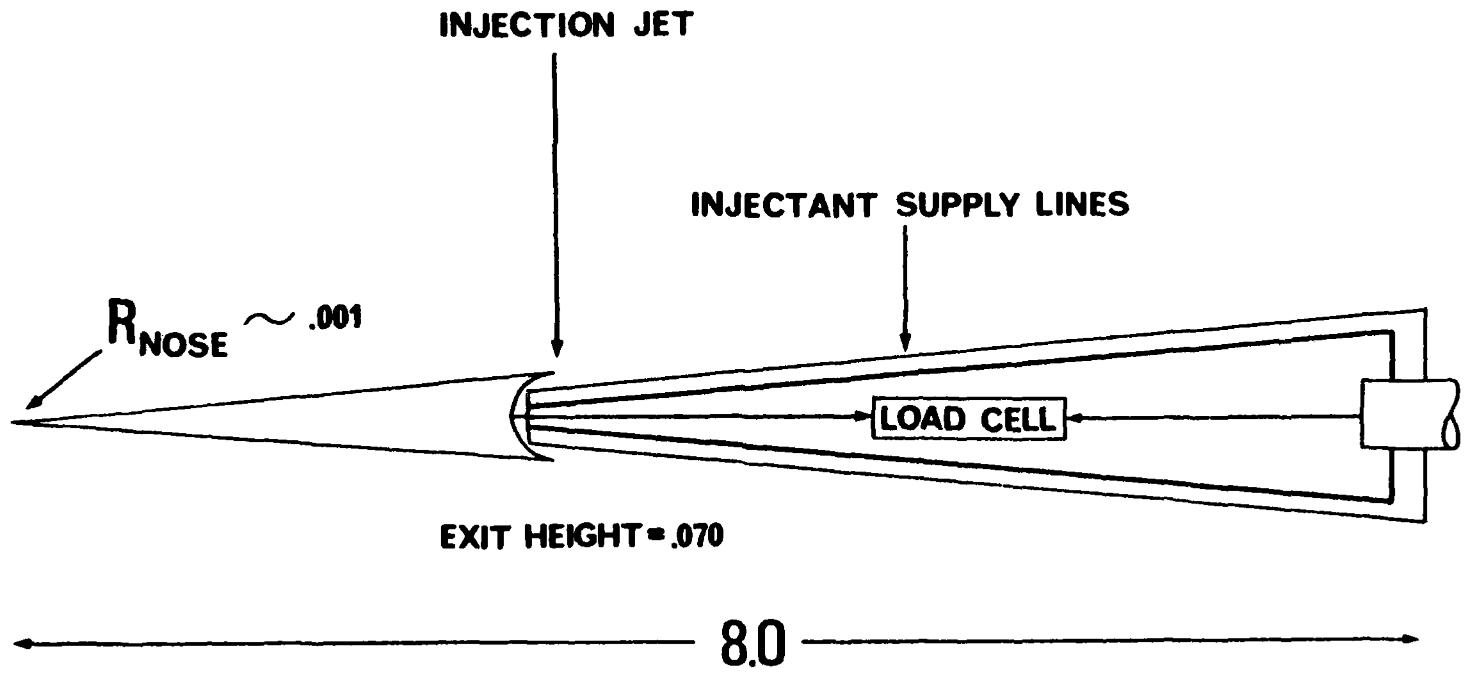
During Phase I of this research, the aforementioned model was immersed in a low density chamber shown in Figure 9 which allowed altitudes up to 300,000 ft. to be simulated. A small nozzle upstream admitted the introduction of a supersonic freestream although specific flight conditions have yet to be simulated. Figure 10 presents a typical shadowgraph flowfield visualization of the plume at highly underexpanded conditions.

Conclusions

Results of the Phase I tests on the wall jet hypervelocity interceptor model clearly indicate that the partially-bounded nozzle exhaust configuration does not reduce thrust generation efficiency and could have a beneficial controlling/mitigating effect on the plume billowing of hypervelocity interceptor propulsion jets at high altitude. In addition, the ability to generate sideforces with the same generic configuration and allow for staging, wherein the forebody separates from the afterbody at the opportune time, has been outlined. Extensive Phase II wind tunnel tests at various Mach numbers, altitudes, jet Mach numbers and pressures, and angles-of-attack have been planned and are the subject of a forthcoming proposal.

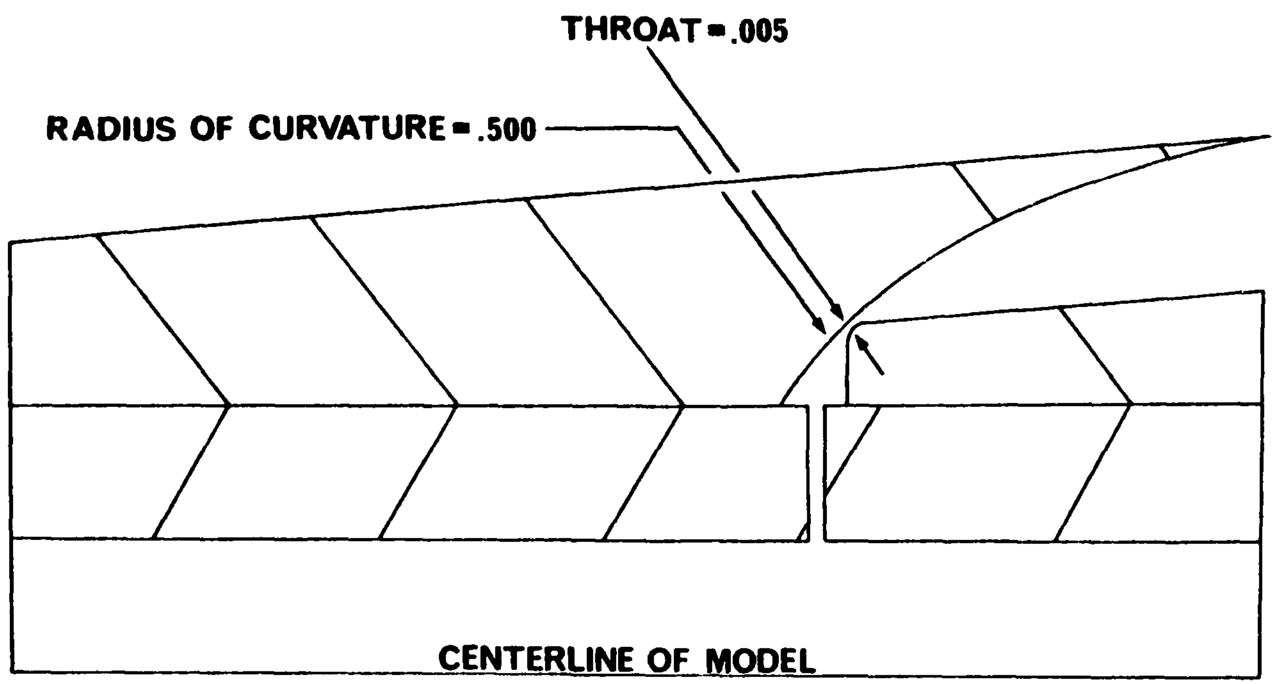
SCHEMATIC OF PRIMARY EXPERIMENTAL MODEL

FIG. 1



ENLARGED VIEW OF INJECTION PORT

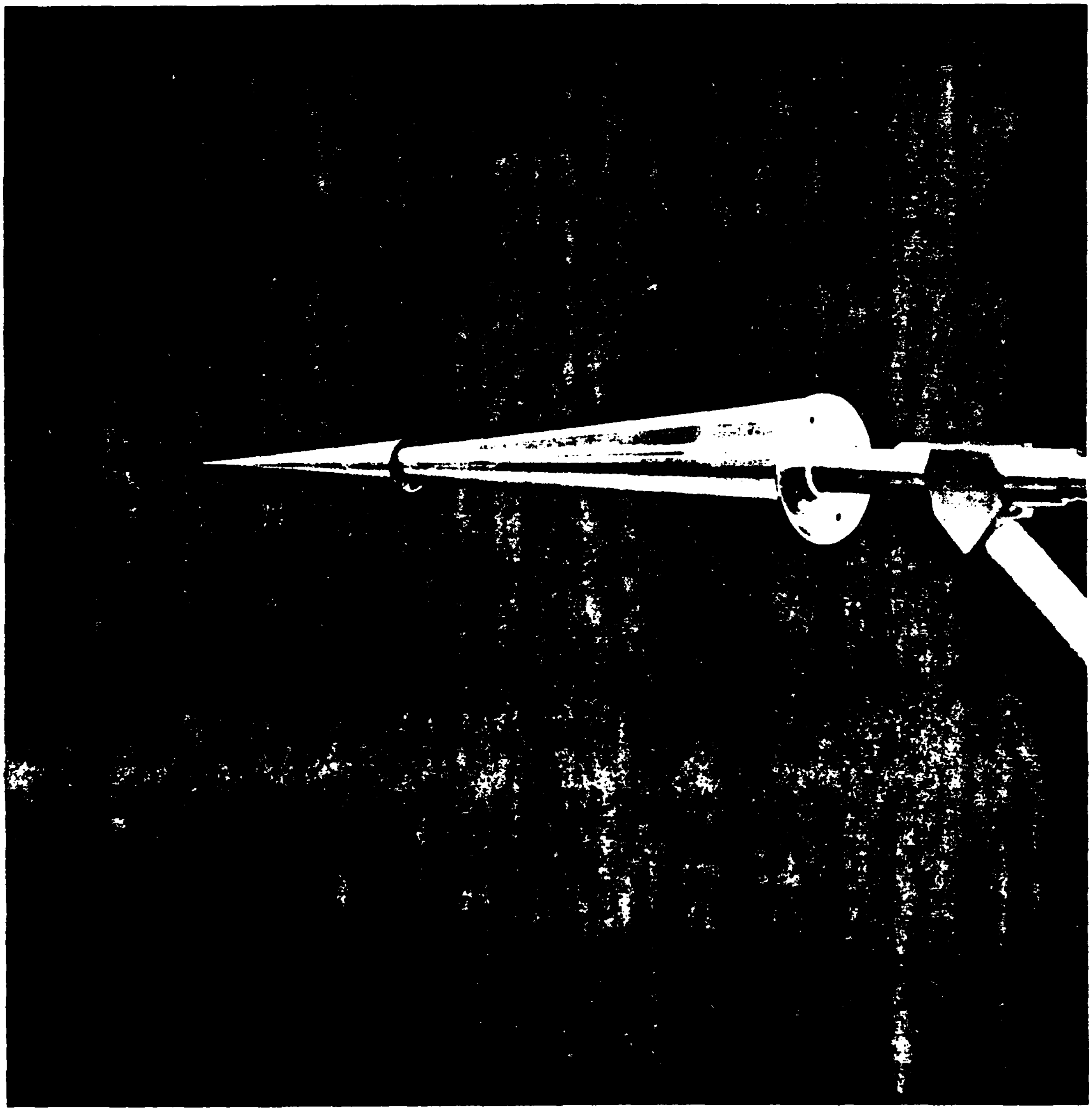
FIG. 2



12:1 SCALE

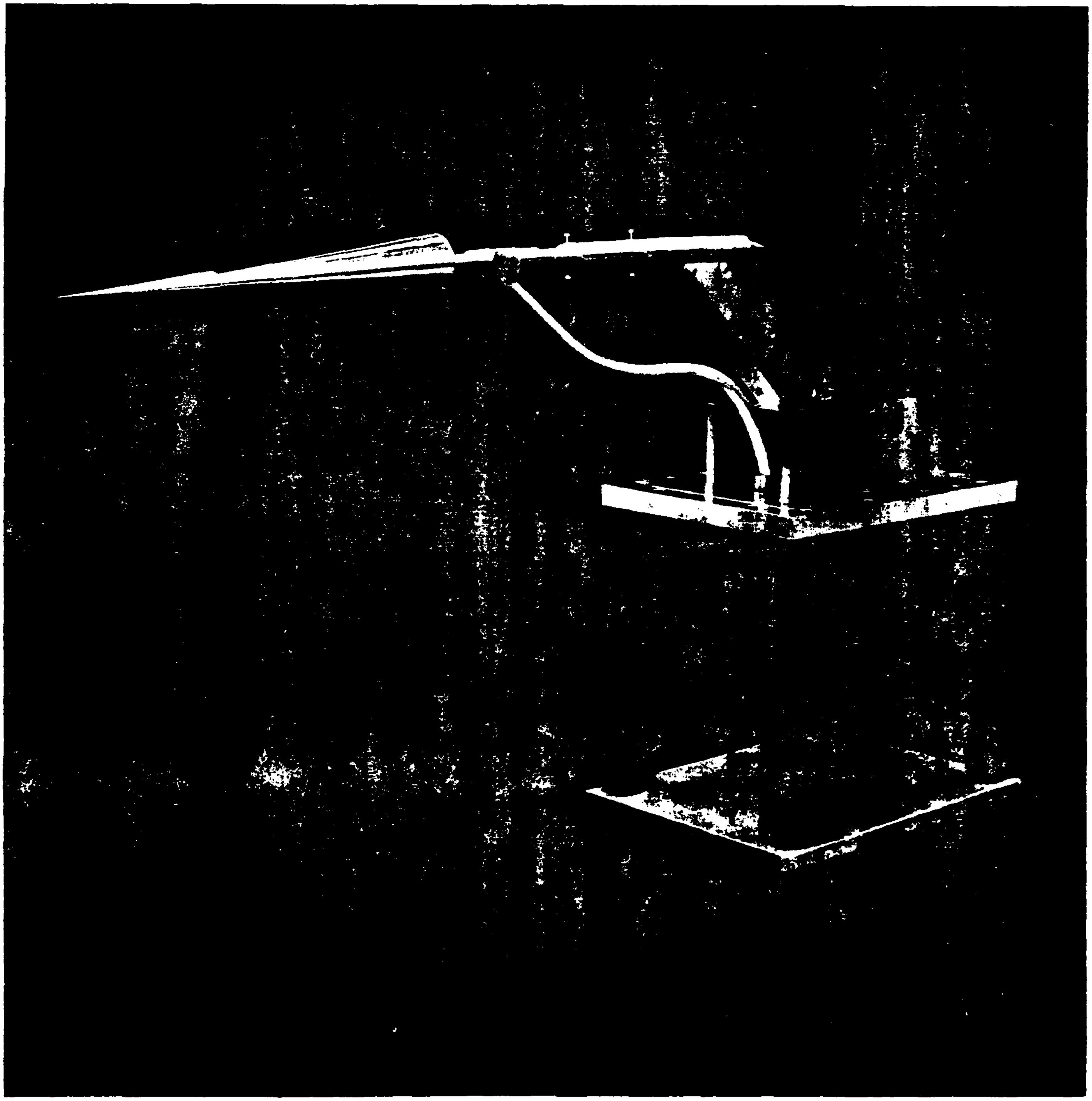
PHOTOGRAPH OF INJECTION MODEL

FIG. 3



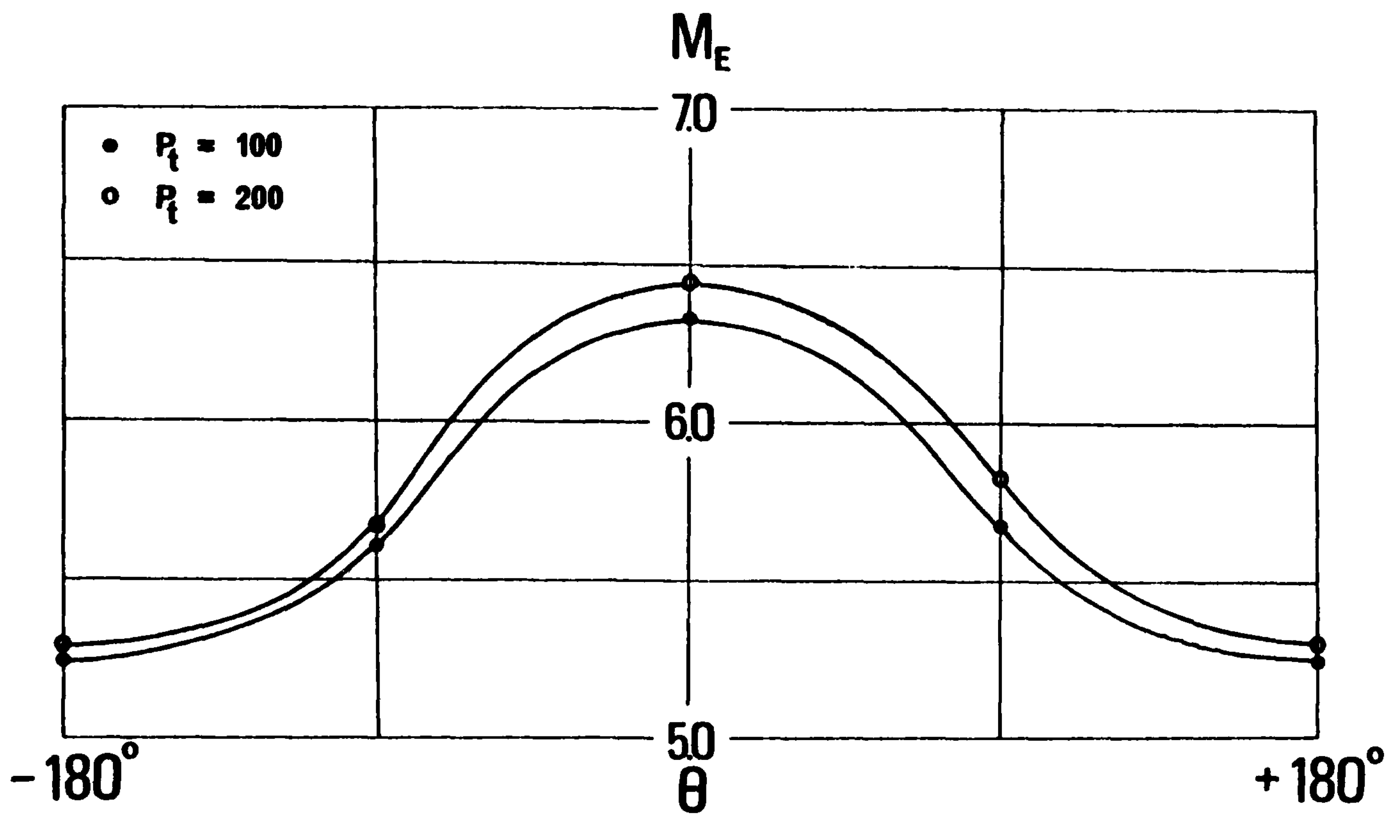
PHOTOGRAPH OF INJECTION MODEL

FIG. 4



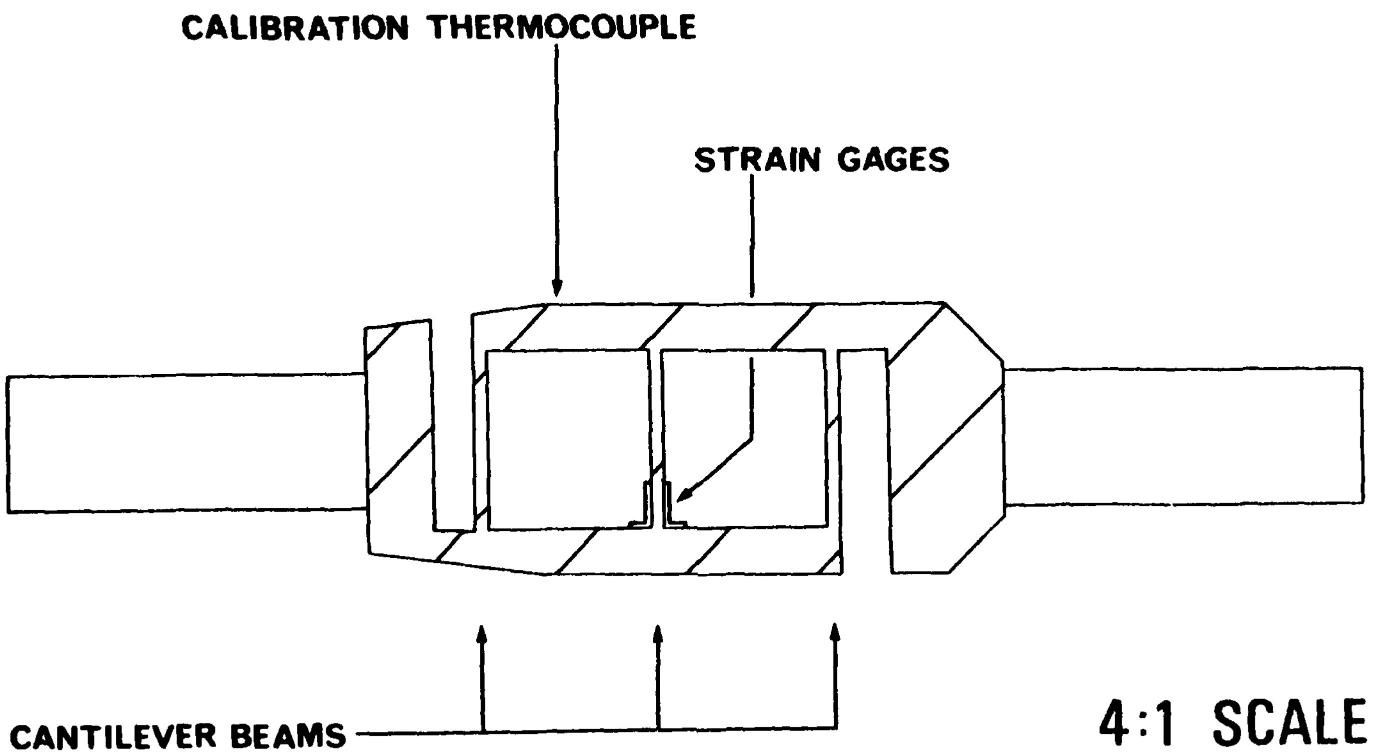
MACH NUMBER DISTRIBUTION OF INJECTION JET ON PRIMARY MODEL

FIG. 5



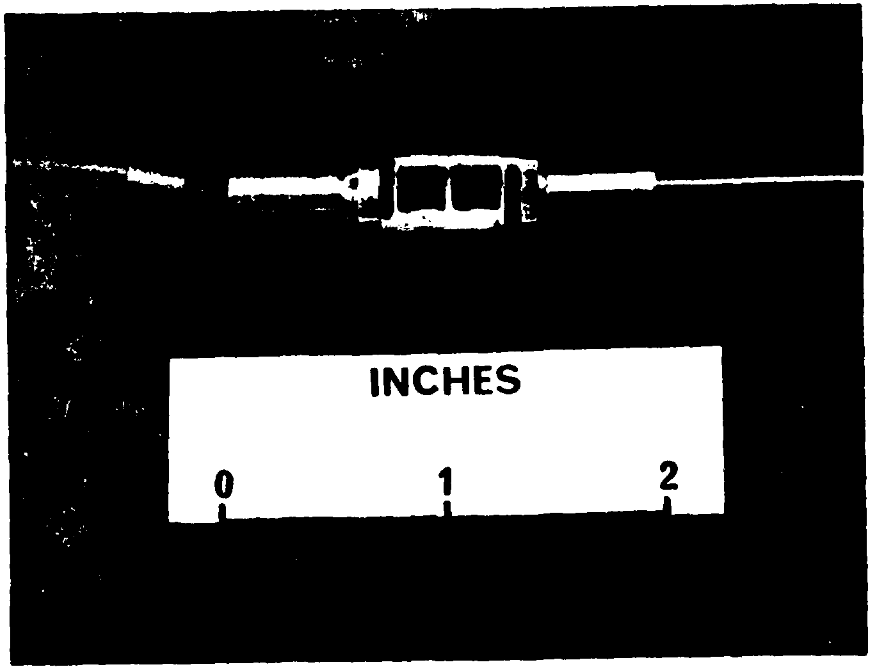
STRAIN GAGE LOAD CELL

FIG. 6



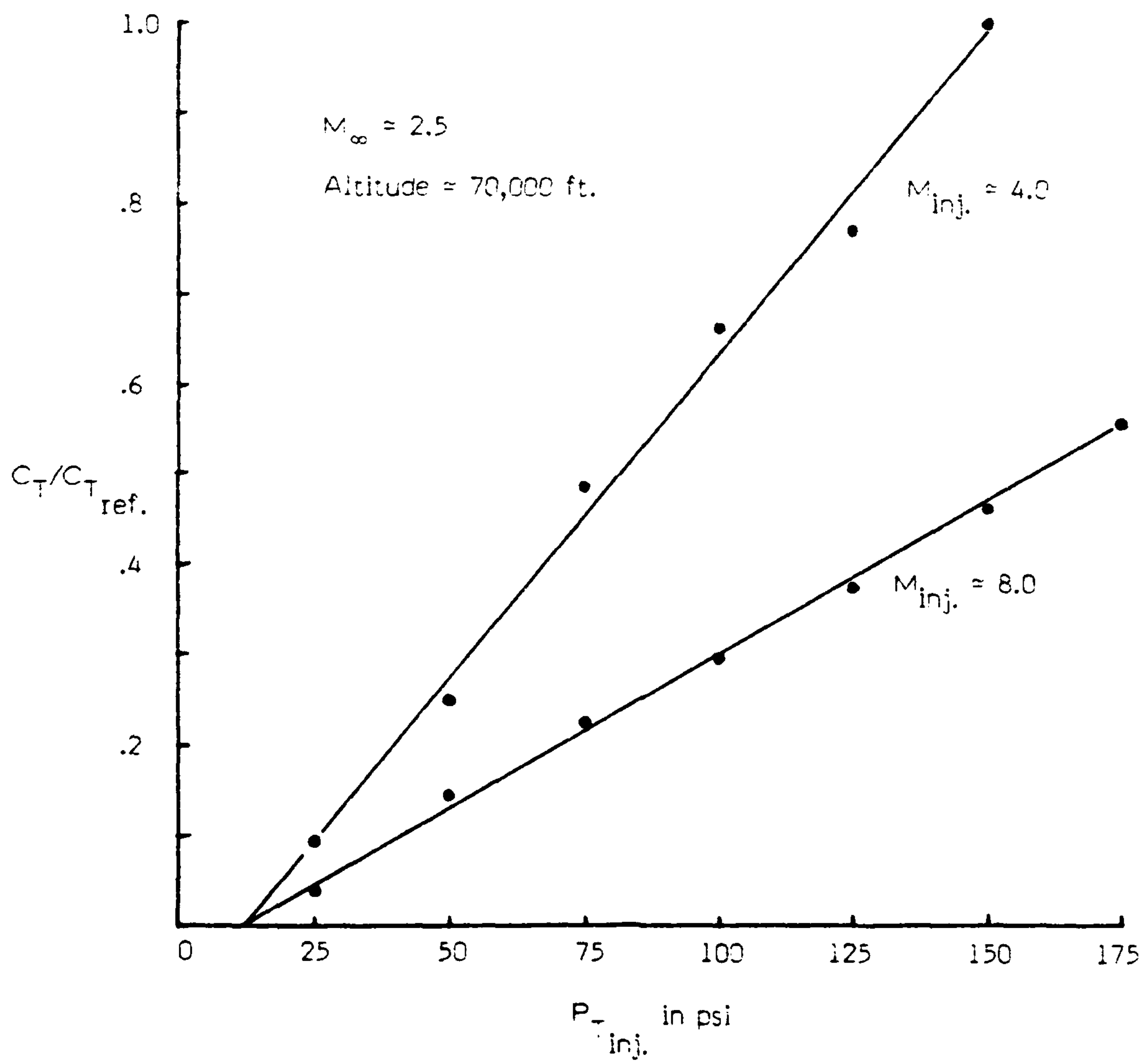
STRAIN GAGE LOAD CELL

FIG. 7



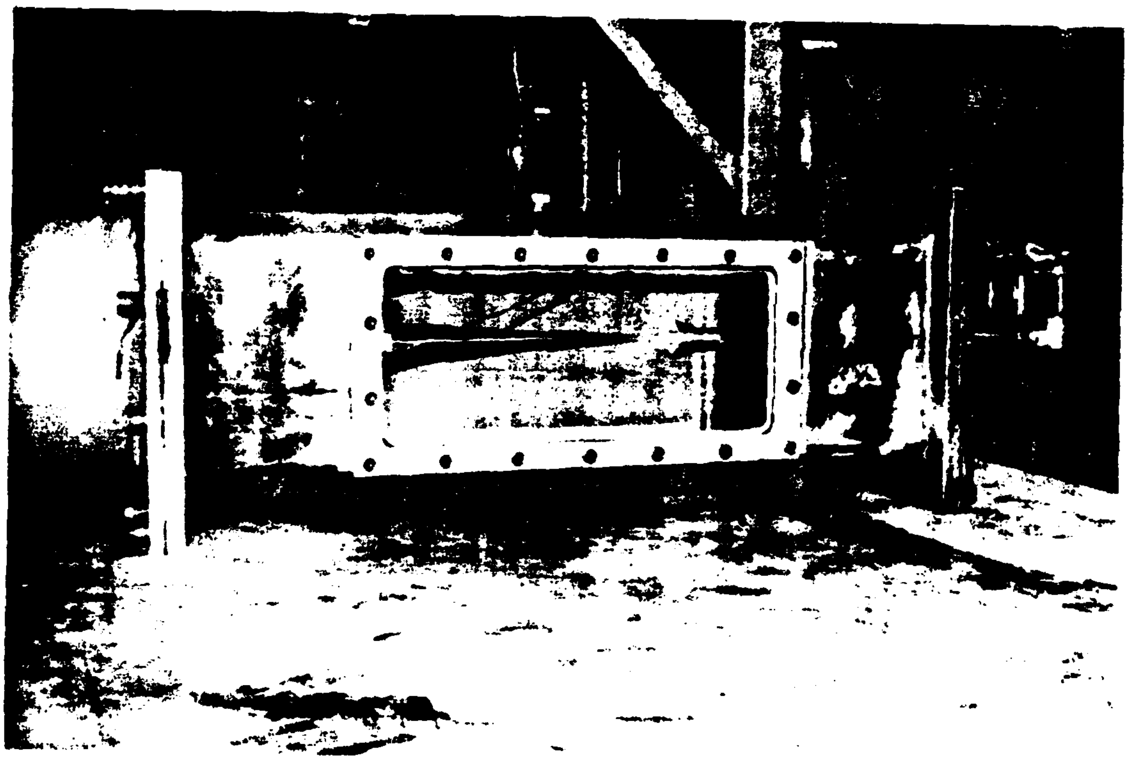
THRUST COEFFICIENT VS. INJECTION PRESSURE

FIG. 8



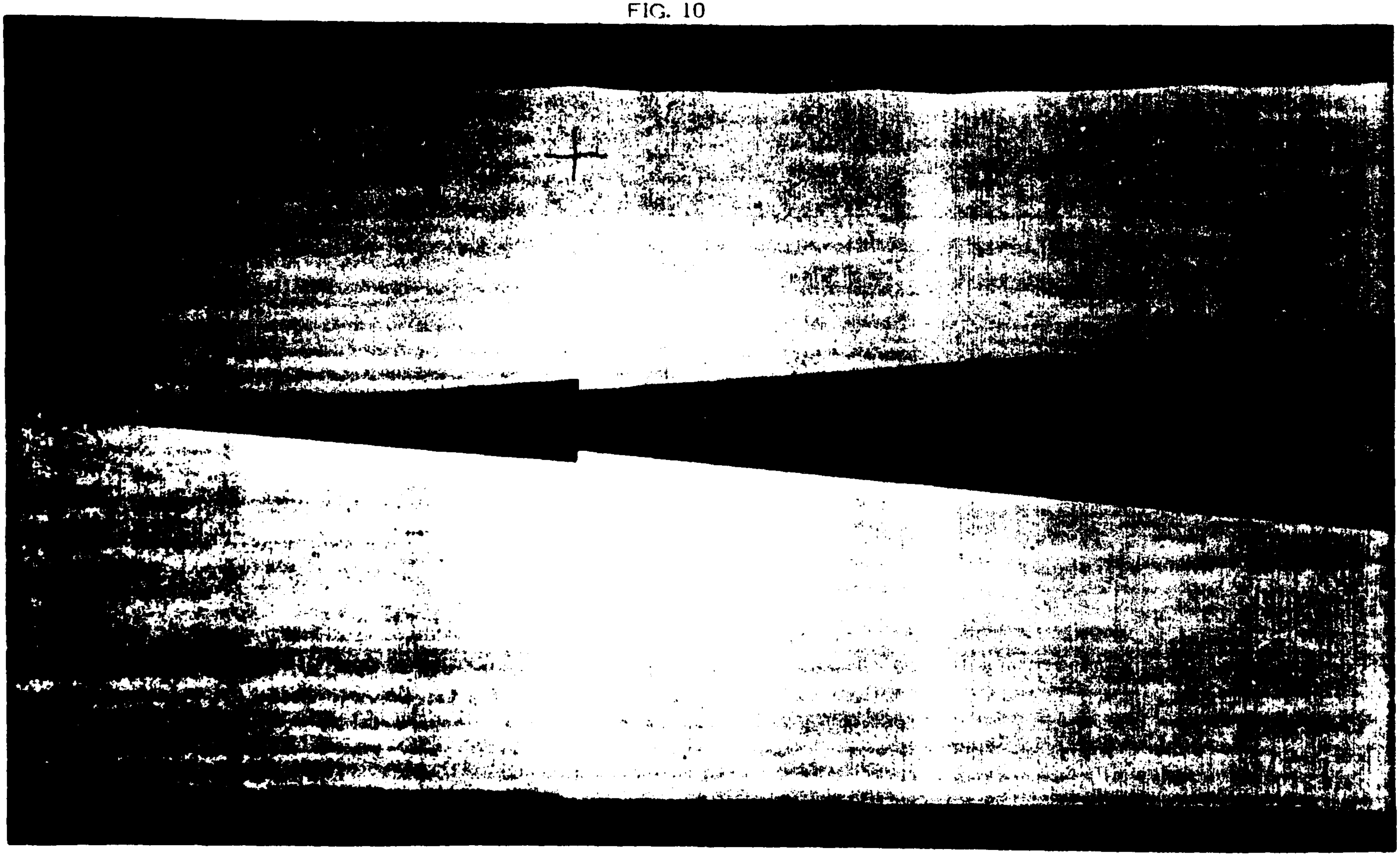
PHOTOGRAPH OF EXPERIMENTAL SET-UP

FIG. 9



SHADOWGRAPH OF INJECTION FLOWFIELD

FIG. 10



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